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Research Article

Utilizing Subsurface Drip Irrigation and Conservation Tillage in Cotton Production Systems

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Ground water resources for irrigated agriculture are becoming increasing limited in semiarid regions of the world. Subsurface drip irrigation (SDI) and a no-till conservation tillage system were evaluated over 3 years on cotton (*Gossypium hirsutum*, L.) production and fiber quality in north Texas. Subsurface drip irrigation significantly increased cotton yields over that from furrow irrigation in 2 of 3 yr. When averaged over 3 yr, the cover crop treatments on 1 and 2 m drip line spacing and a 100% ET replacement yielded numerically more than the companion treatments without a cover crop. Across years, the SDI treatments significantly increased loan values by an average of \$0.045 kg^{-1} over furrow-irrigated cotton. Within SDI, deficit irrigation did not appear to affect cotton yield in proportion to the amount of restricted irrigation. In 2003, a 50% reduction in ET replacement under conventional tillage reduced yield only 22%, indicating that a 100% ET replacement may not be necessary to produce economically acceptable yields. Results from this study provide preliminary evidence that cover crops may actually prove beneficial under SDI systems and could play a role in developing best management practices that incorporate conservation tillage practices.

1. Introduction

Agriculture accounted for nearly 65% of world's water consumption in 2000, while industry and urban needs accounted for an additional 31% [1]. As world population increases, so has irrigated acreage [2]. Increasing agriculture and urban demands for limited water resources in semiarid environments has placed considerable pressure on state and local governments to conserve and manage this valuable resource. Since agriculture is a major consumer of water for food and fiber production, it becomes critical to use efficient water delivery systems to crops, in addition to utilizing the most drought-tolerant water-efficient crops, cropping systems, tillage practices, and plant genetic materials available in sustainable crop production. Subsurface drip irrigation (SDI) is perhaps the most efficient water delivery system to roots of plants, producing crop yields equal to or greater than other irrigation methods and, in many cases, requiring less water and improved water-use efficiencies [3–6]. In regions where irrigation well capacities are low and in cases where available irrigation water is saline or where shallow water conditions are saline, SDI, compared with surface irrigation systems, offers the greatest potential to increase yields and irrigation water use efficiency [7–10]. In addition to greater water-use efficiencies, fertilizer N and P applications rates may be lowered using SDI systems where N and P are applied through the system; that is, less nutrients are required to maximize yield, thus improving profitability [11–14].

In the semi-arid Texas Rolling Plains, water is the most limiting factor in cotton production. In 2006 (limited precipitation) and 2007 (adequate precipitation), irrigated cotton comprised only 15% of total cotton acreage but accounted for 24% to 50% of total lint production [15]. Irrigated crop yields can be 2 to 4 times higher than those from dryland production and much more stable from year to year. Crop failure under dryland production is always a threat as realized in 2006 when nearly half the dryland crop failed. By comparison, 98% of irrigated cotton survived [15].

Ground water resources of the underlying Seymour aquifer are nearly fully utilized; so expanding irrigated acreage using current irrigation systems (pivot and furrow) is extremely limited. Irrigated cotton production can only expand through the use of more efficient irrigation systems and increased management of ground water resources. Furrow and older pivot irrigation systems are relatively inefficient water delivery systems compared with SDI, particularly under limited water supplies. Furthermore, irregular-shaped fields cannot be efficiently irrigated with pivots and furrow irrigation systems. Utilizing SDI technology has the potential to measurably increase cotton yields and expand irrigated production acreage in hard-to-water fields, thereby increasing the standard of living for rural families and strengthening rural economies. However, little acreage has been placed under drip in the Rolling Plains compared with other parts of the country. One deterrent to establishing SDI over current irrigation systems is the high cost of installation. However, SDI systems have been shown to be competitive with other irrigation systems when the value of crop grown, field size, system longetivity, and other environmental and management concerns are taken into account [16, 17].

In the Texas Panhandle, Colaizzi [18] and Colaizzi et al. [9] showed that SDI resulted in greater lint yield at 50% or less evapotranspiration (ET) replacement, whereas LEPA (low-energy precision application) and spray performed are equal to or greater than SDI with higher irrigation. Darusman et al. [19] in Kansas with corn (*Zea mays* L.) and Bhattarai et al. [6] in Australia with cotton also concluded that 100% crop ET replacement was not necessary to optimize plant productivity and water-use efficiency. Overirrigation can lead to oxygen deficiency, excessive runoff following a high rainfall event, and increased internal drainage that can transport nitrates and other nutrients deeper into the soil profile and ground water.

A major problem with SDI in semi-arid areas with years of limited spring rainfall is crop establishment due to insufficient and uneven distribution of moisture as water moves upward and outward from the drip laterals to the seed zone [20–22]. Usually a "planting rain" is needed to ensure uniform crop establishment, and this is the normal situation for the Texas Rolling Plains. Seedling establishment problems occur with greater frequency under SDI in the more arid areas of far west Texas and the Texas Panhandle. Current studies on the Texas High Plains have focused on bed design or soil amendments to enhance crop emergence, and in Australia, scientists studied SDI configurations and an experimental polyethylene/geotextile product laid with the drip tape to enhance water movement away from the source to the seed [20] or polyethylene foil placed below the drip tapes to prevent water loss through deep percolation [1]. Alternatively, placing drip tape at shallow soil depths (15–20 cm), prewatering, and planting directly over the drip tape offer increased probability for crop establishment, since water is not required to travel as far to the seed zone [22]. However, driplines in every row will increase SDI installation costs, but it also reduces the application time for a given amount of water to be applied to a field.

Incorporating conservation tillage practices in an SDI system has potential to capture rainfall to further augment water savings provided by SDI, while protecting seedlings from damaging winds, limiting weed competition, and reducing the harmful effects of wind erosion. However, there is very limited information on cotton production in semiarid environments using no-till and conservation tillage with terminated cover crops in an SDI system; yet conservation tillage systems may offer additional water savings, reduced soil erosion, and improved crop establishment. In a two-year study in South Carolina, Camp et al. [23] studied cotton production under no-till culture with SDI. Although there were no yield differences among three irrigation treatments, they noticed that there was considerable soil compaction at shallow depths of <5 cm that restricted root growth. The authors assumed that compaction limited the efficacy of SDI and suggested that on their soils, strategies must be developed to reduce soil strength in order to optimized no-till production with SDI. Over time, no-till systems with a terminated cover crop generally result in soils with improved soil structure and increased organic matter. With global positioning and autosteer systems, traffic patterns can be held constant, thereby reducing the area compacted by heavy equipment and presumably improve crop establishment. The objectives of this study were to determine (1) whether no-till with a terminated cover crop (a conservation tillage practice) and SDI were compatable in maintaining or improving cotton yields and (2) determine the effect of deficit irrigation, with and without a cover crop, on cotton production and lint quality.

2. Materials and Methods

In 2002, a 12.1-ha site at Munday, TX (33 19′ N, 99 34′ W) was utilized to develop science-based research and educate the public on the benefits SDI technology for the Texas Rolling Plains. Prior to developing the site, previous crops included cotton and grain sorghum (*Sorghum bicolor* (L.) Moench) The soil type is a Miles fine sandy loam (fine-loamy, mixed, thermic, Typic Paleustalfs), well drained with granular to weak medium and/or subangular blocky structure. This soil has no salinity problem and the irrigation water is of good quality. The SDI system was designed so water application to each 0.16-ha plot could be individually controlled. Drip tapes were placed 30 to 35 cm below the soil surface and positioned between plant rows. Controlled traffic patterns were used. Plots consisted of 16, 1 m wide rows by 90 m long and could either be irrigated on 1 m or 2 m drip line spacing through a manual cutoff system that closed alternating drip lines. Gated pipe was used to apply water to furrow-irrigated plots. Water meters installed at each plot recorded water use. Irrigation was initiated at the pin-head square of plant development.

In the first study, treatments included irrigation with 1 and 2 m drip line spacing with and without a rye cover crop and furrow irrigation with and without a cover crop. Controllers were programmed to irrigate daily at 100% ET crop replacement (ET_{100}). In the second companion study, all plots were irrigated on 1 m drip line spacing. Treatments included irrigation at ET_{100}, 50% ET replacement (ET_{50}) with and without a cover crop, and furrow irrigation without a cover crop. Treatments were replicated three times in a randomized complete block design. For the conservation tillage plots, cotton was planted no-till into a rye (*Secale cereale* L.) cover crop that was terminated at 50% heading. Conventional-till plots included several disking operations prior to bedding on 1 m centers. Programming utilized the Texas High Plains PET network to generate weekly average ET replacement values for cotton. The seasonal ET values for the 3 yr ranged from a high of 61.6 cm in 2003 (average 0.56 cm day^{-1}) to a low of 60.3 cm in 2004 (average

0.48 cm day^{-1}). A 7-day rolling average, taking rainfall events into account, was used to program the controllers on a weekly basis. Planting dates ranged from May 20 to June 9. SureGrow 215 BG/RR cotton was seeded each year at 16 seeds m^{-1} of row on 1 m row spacing. The Texas Rolling Plains Region has a bimodal rainfall distribution pattern with higher monthly rainfall occurring in the May-June and August-September time frames. The annual rainfall during the 1 May to 10 June planting time period ranged from 102 to 131 mm among years. Consequently, soil moisture at planting through early seedling development was adequate, and we observed no stand establishment problems for any treatment over the course of this study. Cotton received annual fertilizer applications of 45 kg N ha^{-1} and 9 kg P ha^{-1}. Weeds were controlled with herbicides and hand hoeing. A 4-row by 90 m strip from the middle of each plot was machine harvested for yield in late October of each year. Subsamples were ginned, and lint quality and loan analyses were conducted by the Fiber and Biopolymer Research Institute (Texas Tech University, Lubbock).

Since environmental conditions and rainfall patterns in semiarid regions are rarely similar among years, producers are more interested in average results over several growing seasons when considering new production practices. Producers can accommodate minor year to year variations as long as there is a reasonable propability that a new production system will improve their economic returns over time. Therefore, results were analyzed with the Proc Mixed model procedure of SAS (SAS Institute, 1996), using year both as a fixed and as a random variable. Treatment effects were considered different at $P \leq .05$.

3. Results and Discussion

We found it difficult to supply high amounts of water through furrow irrigation. Only 13 to 20 cm of water could be applied during the season due to the short runs and sealing of the soil surface. Water would exit the plots before significant amounts of water could enter the soil profile. However, with SDI we were able to apply 50 to 60 cm of water (based on ET_{100}). The increase in available water is reflected in higher cotton yields during dry years. The capability to supply irrigation water uniformly across a field in a given amount of time with SDI allows all plants to have the same access to the applied water, unlike furrow irrigation where plants on the top end of the field receive considerably more water than plants on the lower end and where soil can be saturated longer, resulting in moderate stress from water logging.

There were substantial differences in seasonal rainfall among years that affected annual lint yields (Figure 1). May to September rainfall in 2003 totaled approximately 20 cm, compared with rainfall totals for the same period of 46 cm in 2004 and 54 cm in 2005 that were above the 30-year average of 28 cm for the same period. Accumulated heat units or $DD_{60's}$ for July and August were higher in 2003 than in 2004 and 2005, reflecting less rainfall, decreased cloud cover, and higher seasonal temperatures in 2003 (Figure 2). Heat units are calculated by averaging the high and low temperature (in

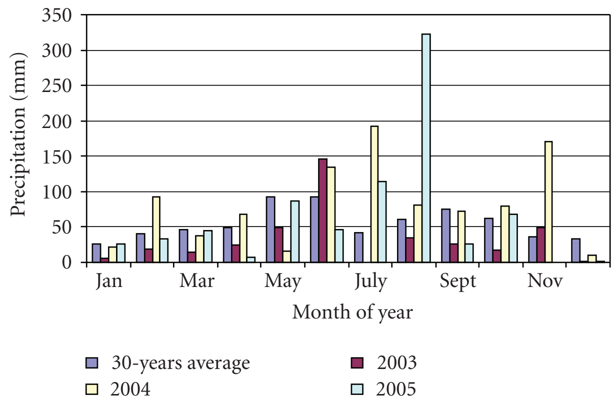

Figure 1: Monthly precipitation totals by year at Munday, Texas, 2003–2005.

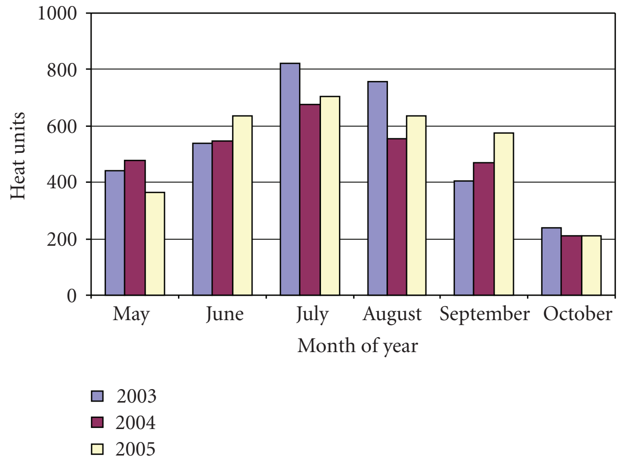

Figure 2: Heat units or $DD_{60's}$ by month and year at Munday, Texas, 2003–2005.

degrees Fahrenheit) for each day and subtracting from 60, the Fahrenheit temperature generally accepted as the lowest temperature at which cotton growth occurs. Approximately 950 accumulated heat units are required to first flower [24].

Environmental conditions in the dry year of 2003 appear to favor high yields when plants are supplied with adequate soil moisture through SDI (Table 1). Although a dryland treatment was not included in the tests, dryland plots were harvested from areas bordering the irrigated treatments. Yields were determined to provide an indication of what dryland production would have been. However, dryland yields were not included in the analyses.

In 2003, there were no yield differences between 1 and 2 m drip line centers (Table 1). The rye cover crop did not influence yield, most likely due to the fact that there was little precipitation to capture during the cropping season. However, the average yield from all SDI treatments exceeded the average yield from furrow-irrigated treatments by 648 kg ha^{-1}, a 48% increase. For comparative purposes only, adjacent dryland yields averaged 750 kg ha^{-1}. The 2 m, no cover crop treatment was set up as the "check" since this

Table 1: Cotton yield response and loan values to subsurface drip irrigation at ET_{100} utilizing 1 m or 2 m drip line spacing and compared with traditional furrow irrigation (Frw), with and without a terminated rye cover crop, 2003–2005 (Munday, TX).

Treatment	Yield			3-yr mean	Percent of check	Loan value[§]			
	2003	2004	2005			2003	2004	2005	Mean
	($kg\,ha^{-1}$)					($/kg)			
1-m, no rye	1950 a[†]	1490 ab	1790 a	1745 A	101	1.22	0.90	1.21	1.11 a
1-m, rye	1950 a	1725 a	1805 a	1825 A	106	1.19	0.95	1.21	1.12 a
2-m, no rye	2015 a	1345 b	1805 a	1720 A	check	1.19	0.97	1.28	1.13 a
2-m, rye	2070 a	1770 a	1790 a	1880 A	109	1.20	0.95	1.21	1.12 a
Frw, no rye	1410 b	1330 b	1680 a	1475 B	86	1.04	0.98	1.20	1.07 b
Frw, rye	1290 b	1275 b	1790 a	1450 B	84	1.04	1.02	1.17	1.08 b
Dryland [‡]	750	805	1570	1040					

[†] Values within a column followed by the same letter are not significantly different at $P \leq .05$.
[‡] For comparison purposes only. Values were not included in statistical analysis.
[§] The marketing loan value is the base price of any program commodity for farm program purposes as determined by the United States Department of Agriculture. For cotton specifically, this base loan value is adjusted by quality premiums and discounts to determine a quality-adjusted base loan value for each cotton sample. The higher the loan value, the higher the quality.

Table 2: Effect of deficit irrigation with and without a rye cover crop on SDI cotton production, 2003–2005 (Munday, TX).

Treatment	Yield			Mean
	2003	2004	2005	
		($kg\,ha^{-1}$)		
1-m no rye ET_{100}	2285 a[†]	1660 a	na[‡]	1970 A
1-m no rye ET_{50}	1880 b	1700 a	na	1790 AB
1-m with rye ET_{50}	1670 b	1570 a	na	1620 B
Furrow no rye	1130 c	1320 a	na	1225 C

[†] Values within a column followed by the same letter are not significantly different at the .05 probability level.
[‡] Not available. Deficit irrigation could not be maintained due to high rainfall and flooded conditions during the growing season.

is the predominant drip line spacing and tillage practice in limited commercial SDI cotton production in the region.

In 2004, there was no yield difference between 1 m and 2 m drip line centers under conservation tillage (Table 1). However, cotton on 2 m centers with rye yielded significantly more than cotton grown on 2 m centers without rye. We also observed that (at least numerically) cotton planted on 1 m drip line spacing with conservation tillage yielded more than cotton grown under conventional tillage and 1 m drip line spacing.

In 2005, 44 cm of rainfall were recorded at Munday during July and August, resulting in the study area being flooded twice, once in July and again in August. Irrigation (both furrow and drip) was terminated during the prolonged wet periods until soil conditions improved. With excessive rainfall during the growing season, it was not surprising that yield differences among drip line spacing, furrow irrigation, and tillage practices were minimal. The higher 2005 dryland yield reflects the above-average rainfall received late in the season (Table 1).

When data were averaged over the 3-year period (year as a random variable), cotton grown under SDI yielded significantly more than cotton grown under furrow irrigation by nearly 330 $kg\,ha^{-1}$ (Table 1). There was a positive numerical trend for cotton to yield more on both 1 m and 2 m drip line spacing with a cover crop when plants were grown under ET_{100}.

Loan values were also determined for cotton grown under different management systems (Table 1). Across years, the SDI treatments significantly increased loan values by an average of \$0.045 kg^{-1} over furrow-irrigated cotton.

A 100% crop use ET replacement through SDI may not be necessary to maximize yield. In 2003, a deficit irrigation study was initiated to determine the effects of a 50% reduction in ET replacement on cotton yield. Table 2 shows the effect of deficit irrigation (ET_{50}) on cotton yield at Munday, TX, for 2003 and 2004.

In 2003, a dry year with the highest ET demand, a 50% reduction in ET replacement (average yield from plots with and without rye) reduced lint yield 22% compared to ET_{100} yields from the 1 m drip line spacing without rye (Table 2). The negative yield trend with a cover crop at ET_{50} is presumed to be due to the fact that a cover crop must extract soil moisture to maintain plant growth, resulting in a greater soil moisture deficit than that in plots without a cover crop, hence, a somewhat reduced cotton yield. In 2004, a year with adequate summer rainfall, there was no significant reduction in yield with ET_{50} compared with the ET_{100} treatment. A high rainfall event in late July most likely augmented water supplied through the drip system. Rainfall in 2005 was excessive at Munday and deficit irrigation could not be maintained; so this study was abandoned. Our 2003 and 2004 results differ from those by Camp et al. [23] in the higher rainfall region of South Carolina. In their 2-year study, these researchers observed no differences in cotton yield when irrigation was reduced by half. Presumably, there was adequate precipitation or soil moisture reserves during the growing season to maximize lint yields.

Our results indicate the importance to continue research on deficit irrigation in semiarid environments to identify the degree of deficit irrigation that a crop could tolerate and yet maintain economical yields and lint quality on less water. Deficit irrigation may allow producers to expand irrigated crop production to maximize a farm's ground water resources and enhance economic returns.

4. Conclusions

Subsurface drip irrigation significantly increased cotton yields over that from furrow irrigation in 2 of 3 yr. When averaged over 3 yr, the cover crop treatments on 1 and 2 m drip line spacing and ET_{100} yielded numerically more than the companion treatments without a cover crop. Although not significant, results from this study provide preliminary evidence that cover crops in an ET_{100} irrigation program may actually prove beneficial under SDI systems in semiarid environments and could play a role in developing best management practices that incorporate conservation tillage practices. On average, the cotton loan value from SDI treatments was significantly higher than cotton grown under furrow irrigation by $\$0.045\,\text{kg}^{-1}$. Deficit irrigation did not appear to affect cotton yield in proportion to the amount of restricted irrigation. In 2003, a dry year, a 50% reduction in ET replacement under conventional tillage reduced cotton production 22%, indicating that 100% ET replacement may not be necessary most years to produce economically acceptable yields. Over the 3-year study period, we did not observe any problem with stand establishment and seedling development in either conservation- or conventional-till systems under SDI in the Texas Rolling Plains region due to adequate spring rainfall each year. Long-term studies that include a series of deficit irrigations and various tillage systems are currently in progress to develop best management practices under SDI in semiarid environments.

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